FUNDAMENTAL COMMUNICATION RANGE LIMITATION OF ULTRA WIDEBAND COMMUNICATIONS FOR MILITARY APPLICATION

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ABSTRACT

An analysis of ultra wideband (UWB) channel capacity as a function of communications range is provided in this paper. Potential military application of UWB communications are indicated based on this analysis, with particular emphasis on unmanned systems. The relevance of UWB communications for ground-to-ground or air-to-ground applications includes low probability of interception or detection (covertness), relative immunity to multipath effects, large spatial capacity compared to other wireless systems, simultaneous precision ranging and communicating, and extremely low transmit power which reduces the possibility of interfering with other radio systems. Implementation challenges for advanced UWB applications are briefly noted.

1. INTRODUCTION

1.1 UWB Communications and Unmanned Systems

The application of UWB communications to achieve unmanned ground vehicle (UGV) / unmanned aerial vehicle (UAV) collaboration was explored during a recently completed Phase 2 Small Business Innovation Research (SBIR). The goal of this effort was the design of a UWB transceiver to enable video transmission from a UGV to an operator control unit using a UAV as a communications relay. The culmination of the SBIR was a demonstration at Redstone Arsenal, AL of a UWB video transmission from a UAV down to a ground station at a range of approximately 0.5 km. In addition, three UWB radios were configured for a 1.5 km ground-to-ground communications relay link. Time Domain Corporation (Huntsville, AL) received the SBIR 2004 Quality Award for this effort.

1.2 Outdoor UWB Wireless Network Capacity

The practical capacity of outdoor UWB wireless networks at tactical ranges has received scant attention in the engineering community (Zhao and Haimovich, 2001). The methodology to determine the UWB channel capacity as a function of range is based primarily on Shannon's information theorem (Shannon, 1948) and Federal Communication Commission (FCC) constraints (FCC, 2002). Simplifying assumptions concerning atmospheric losses and antenna characteristics are used to postulate hypothetical communication link budgets. This methodology is directly relevant for specifying realistic applications of UWB communications for unmanned system initiatives, which are an integral part of the Future Combat System. An assessment is made for specific areas such as UGV/UAV interoperability, UAV to UAV communications, and collision avoidance for small UAVs. The analysis presented in this paper has been applied for determination of technology transition to evolving war fighting systems.

2. METHODOLOGY

The Shannon information theorem

$$C = B \log_2 (1 + S/N) \quad (1)$$

where C is maximum channel capacity (bits/sec), B is channel bandwidth (Hz), S and N are signal and noise power, respectively (watts). The Shannon equation refers to inputs or transmissions as a function of time, so that its use to determine UWB data rate as a function of communication range represents an approximation of a discrete process. Equation (1) is equated with the ratio of the energy per bit (E_b) to single-sided power spectral density of white noise (N_o) for a perfect communications channel with FCC limits. This results in an estimate of the fundamental limitation of data rate as a function of range:

$$M = B \log_2(1 + (1.687 * 10^{12}/B * R^2)) \quad (2)$$

where R is communications range (m) and M is data rate (bits/sec). The units for E_b are Joules or watts-sec, and the units for N_o are watts/Hz/sec. The E_b/N_o term is the ratio of pulse energy to thermal noise per Hz. A detailed derivation of Equation (2) may be found in a technical report (Levitt, 2004).

3. UWB CHANNEL CAPACITY AND COMMUNICATIONS RANGE

The simplifying assumptions are ideal modulation, no system losses, FCC emission limits, and the FCC main frequency band. The basic characteristic of UWB communications is revealed in Figure 1, namely very high data rates at relatively short ranges, with low data rates at longer ranges. The region to the right of the curve is considered to be unavailable, while the possible operating region is to the left.

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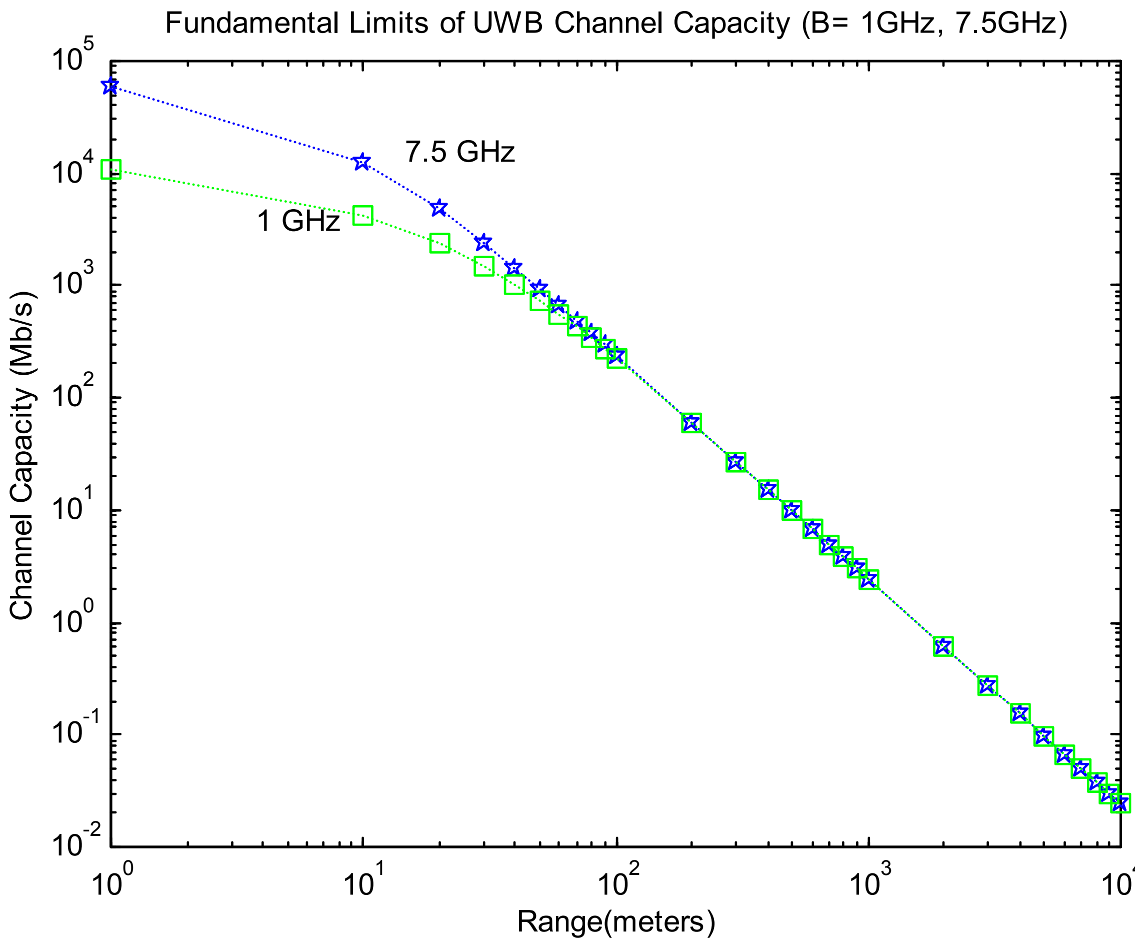

Fig 1. Fundamental limits to UWB channel capacity.

4. DISCUSSION

Based on Fig. 1, data rates of roughly kilobits/sec at a few km (assuming perfect communication channels), especially with the possibility of simultaneous ranging and communicating, could be a viable approach for collision avoidance and data exchange among small UAVs. The use of large antennas and receivers to achieve longer ranges (approximately 10 km) is not practical with current UAV payload limitations, and compromises secure communications since power levels would have to be substantially increased.

Concern about interference from other narrowband systems is still a contentious issue. However, UWB centrally controlled networks with multiple short range links, advanced digital filters (notch filters), and more adaptive receivers and antennas could lead to changes in FCC restrictions. Increases in data rate as a function of communications range could be realized by pulse compression, advances in broadband non-resonant antennas, the use of multiple antennas, improved spectral efficiency (such as higher order modulation techniques), and the use of multiple input/multiple output techniques.

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